3-3 B

MSC INTERNAL NOTE NO. 64-EG-19

PROJECT APOLLO

EXTENSION OF INVESTIGATION OF CSM RESCUE OF LEM

Prepared by: Charles R. Price
Charles R. Price

Approved: Jack Funk
Jack Funk
Chief, Theoretical Mechanics Branch

Approved: Robert C. [illegible]
Chief, Guidance and Control Division

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

September 10, 1964

EXTENSION OF INVESTIGATION

OF CSM RESCUE OF LEM

SUMMARY

The problem of an inactive LEM in a clear pericynthion elliptical orbit being rescued by the CSM is studied on an impulsive maneuvers basis. Constraints due to allowable characteristic velocity, LEM systems contingency time, safe pericynthion altitude, and initial occultation of CSM from both LEM and earth are imposed. Results indicate that by a careful choice of LEM apocynthion altitude a rescue maneuver is available for any initial phase angle if launch can be made into the CSM orbital plane. However, for out-of-plane launches of one degree of more there exists a range of initial phase angles for which there is no rescue regardless of LEM apocynthion altitude.

INTRODUCTION

A brief investigation of CSM rescue of an inactive LEM from lunar orbit within design fuel and contingency time limits has been reported in reference 1. In this reference it was assumed that (1) the LEM was launched into a circular orbit before becoming inactive, and (2) the CSM maneuvers were initiated immediately upon LEM circularization, if necessary. These two assumptions may, in reality, be invalidated. First, LEM may not be capable of performing a circularizing (second) impulse, in which case the LEM must be rescued from an elliptical orbit. And second, the CSM may initially be occulted from earth and LEM preventing transmission to the CSM the information that rescue maneuvers should be initiated, thus causing a delay until CSM is again in contact with earth (or LEM). It is the purpose of the present study to extend the investigation of reference 1 to include the effects of these two operational constraints, namely, LEM orbit ellipticity and delay in rescue initiation.

STATEMENT OF THE PROBLEM

In generalizing the initial conditions of the rescue problem the elliptical analysis begins with LEM in a clear pericynthion orbit with a velocity other than the circular velocity which defined the initial conditions of the circular study (reference 1). This more realistic approach defines a valid rescue as one which occurs within the allowed contingency time from the termination of the powered launch of LEM. After this launch no more maneuvers can be performed by the LEM. Hence, CSM must intercept and rendezvous with the LEM and return to earth from the LEM orbit.

The type of rescue maneuver used throughout this study is a restricted version of the modified delayed transfer used in the circular analysis of reference 1; i.e., CSM ascends or descends, as required, to a new altitude (Parking orbit) and coasts until proper phasing for the intercept transfer is obtained. A restriction that intercept occur at an apsis of the LEM orbit is made so that all transfers between orbits are Hohmann or cotangential transfers as illustrated in figure 1. This restriction is imposed since such transfers are near ΔV (fuel) optimum transfers, as shown in reference 2, and also, to simplify on-board procedures.

Employment of this rescue maneuver in the elliptical study followed readily from the circular results where such maneuvers bounded a region of initial relative states for which the velocity allowance and contingency time did not allow coverage. One boundary existed because of the velocity limit on the CSM ascending mode; the other existed because of the same limitation of the descending mode. Therefore, for any phase angle and altitude combination that does not fall within this no-rescue zone, some attainable parking orbit exists to which the CSM can transfer in order to intercept the LEM within the allowable contingency time.

The foregoing logic is perturbed in the event that CSM is out of sight, and correspondingly out of communication, with both LEM and earth at time of LEM lift-off and is consequently unaware of the event. Such a situation would require a delay of the initiation of rescue maneuvers until CSM was again in contact with the earth. This delay can vary from zero time to one hour for the nominal CSM orbit. Any such delay would decrease usable contingency time by the same amount and require an updating of initial rescue conditions. Such a delay was not included in the analysis of reference 1 but is included in the present study.

SCOPE OF CALCULATIONS

In this study CSM is initially in an 80-nautical-mile-altitude circular orbit and LEM is in an elliptical orbit where pericynthion altitude is 50,000 ft and apocynthion altitude may have a value up to 160 nautical miles. The relative angle between the orbital planes of the two spacecrafts is assumed to be equal to or less than one degree. The impulsive conic calculations used to determine the rescue maneuvers are limited by a velocity allowance of 455 fps (no allowance is made for midcourse guidance corrections) and by a contingency time allowance of 10.5 hours. The contingency time is assumed to begin with the termination of the LEM powered launch and ends with rendezvous with the CSM.

Allowance is made for circularizing after rendezvous and for a typical variation in velocity requirements off the nominal transearth injections. Thus, a small variation may well occur in the Delta V required in rescue maneuvers for any specific Apollo mission.

RESULTS AND DISCUSSION

The results of the circular orbit study reported in reference 1 are reproduced in figures 2 and 3 for the coplanar and 1° out-of-plane cases, respectively. These results illustrate the initial relationship between LEM orbital altitude and phase angle (central angle between LEM and CSM) for which rescue can and cannot be made. Superimposed on the results is the additional region of no rescue incurred by the communications delay when CSM is orbiting behind the moon (as seen from earth). From these results it appears that the communications delay, while increasing the region of no rescue, does not create any severe restrictions to the rescue problem.

Figures 4 and 5 contrast the rescue coverage for the situations arising when LEM can and cannot provide the circularizing impulse on the ascent trajectories with a pericynthion altitude of 50,000 feet. These results include the communications delay. The regions of rescue based on the circular LEM orbits study are also shown in these figures for comparison with the elliptical cases. It is evident from this comparison that rescue coverage is decreased considerably in the elliptical case. That is, the LEM crew has a much higher probability of being rescued if it can perform a second burn to circularize its orbit. In fact, for the 1° out-of-plane elliptical orbit there is a range of initial phase angles (243° to 296°) for which no rescue exists for all apocynthion altitudes considered. This phase angle range of 53° corresponds to a surface stay time of 17.7 minutes to await a desirable phase relationship during each CSM orbital period (122.6 minutes).

As in the circular case the elliptical results may be extended beyond the anytime launch situation to cover the aborts from the Hohmann and powered descents. If the abort occurs during the Hohmann descent and assuming contingency time is measured from pericynthion (where the nominal powered descent would have started) the resulting initial phase angle is -9.4° or 350.6° for a LEM apocynthion altitude of 80 nautical miles. This combination is seen to be covered in figure 3. For aborts after initiation of the powered descent the initial phase angle would range from -9.4° (350.6°) to $+17.0^{\circ}$ (-343.0°) which are covered if the LEM can achieve an apocynthion altitude of at least 20 nautical miles. The feasibility of such rescue maneuvering is probably academic since the landing being aborted, LEM may be assumed to have more fuel and life time than if it had landed.

If the LEM burns out with other than a zero value for flight path angle, the true anomaly of the resulting orbit is also non-zero. The effect of having an initial true anomaly of $+45^{\circ}$ and -45° is shown in figures 6 and 7, respectively. It is seen that rescue coverage is changed slightly.

Since the elliptical rescue study was based on a maneuver with an intercept restricted to LEM orbital apses, it is conservative. In figures 8 and 9 this method is compared with the unrestricted method for circular LEM orbits. The shaded area represents valid maneuvers which are not indicated by the restricted intercept method. This suggests that there may well be valid LEM rescues from elliptical orbits that are not shown in figures 4 and 5. These would require other than Hohmann transfers, however, and are beyond the scope of the present report. Based on the results shown in figures 8 and 9 the inclusion of the other than apses transfer is not expected to appreciably affect the size of the no-rescue zone for the case of elliptical LEM orbit.

Finally, for completeness, a typical coplanar rescue maneuver is illustrated in a schematic in figure 10 and time histories of inertial relative range and altitude are shown in figures 11 and 12.

CONCLUDING REMARKS

An extension of the problem of CSM rescue of the LEM reported in reference 1 has been presented herein for the LEM in an elliptical orbit. Consideration of delay in CSM maneuvering due to lack of communications when CSM is behind the moon is also included. The study based on impulsive conic trajectory calculations indicates that by a careful choice of apocynthion altitude, LEM is covered for the anytime surface abort situation if launch can be made into the CSM orbital plane. As the out-of-plane is increased to one degree, this complete coverage is interrupted for a period of 17.7 minutes every CSM orbital period. Although not described herein, the method by which these results were obtained can be utilized in a ground-based operations program to calculate a specific rescue maneuver if a need for it arises during an Apollo mission.

REFERENCES

1. Price, C. R., and Bennett, F. V.: "A Brief Investigation of CSM Rescue of LEM", MSC Internal Note No. 64-EG-2, February 25, 1964.

2. Rider, L.: "Ascent from Inner Circular to Outer Co-Planar Elliptic Orbits", American Rocket Society Journal, Vol. 30, Number 3, March 1960.

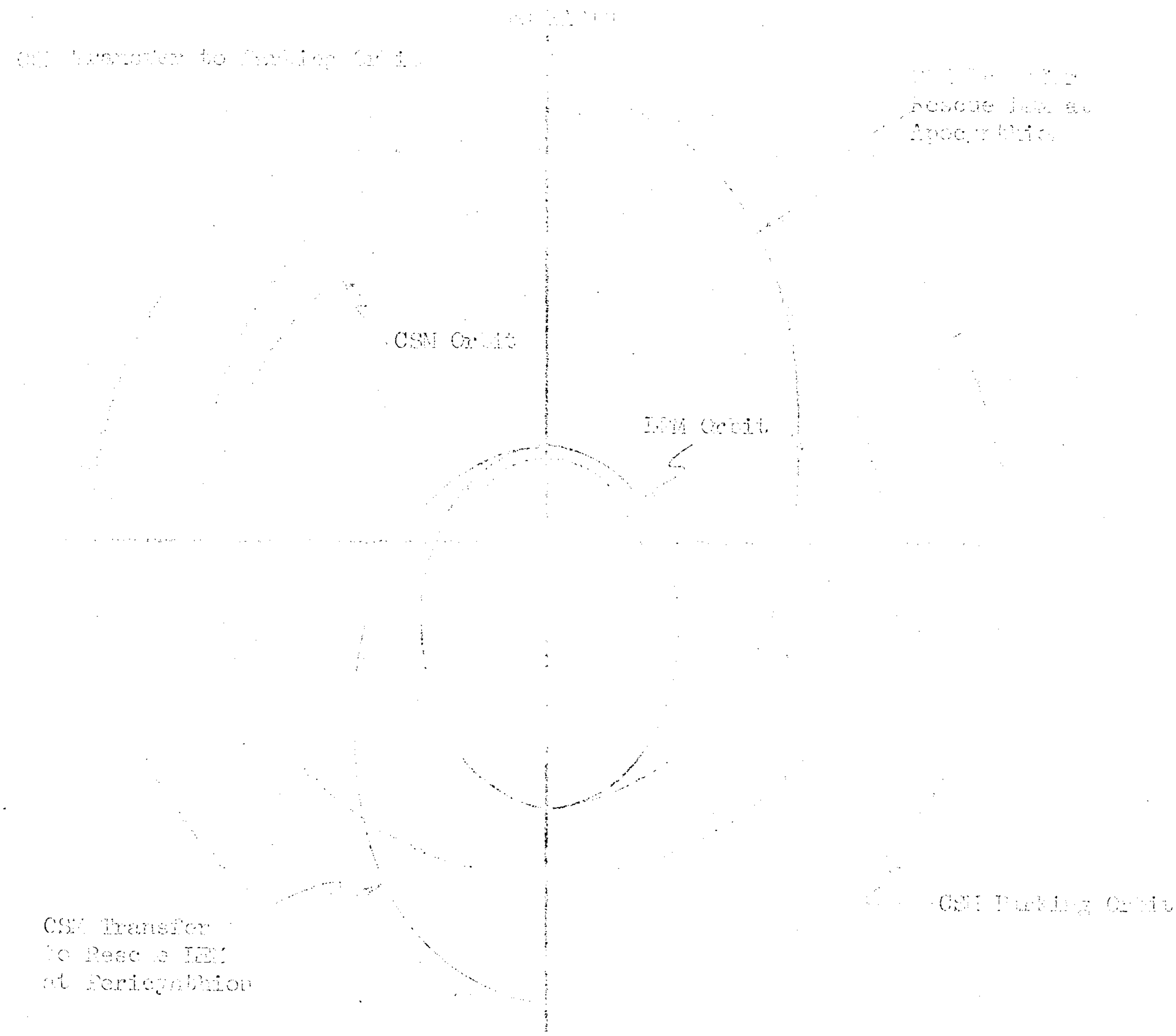

Figure 1.- Sketch of CSM Rescue of LEM Using Restricted Apse Transfers
(All transfers Hohmann)

Figure 2.- Circular LEM Rescue Coverage (Concluded)

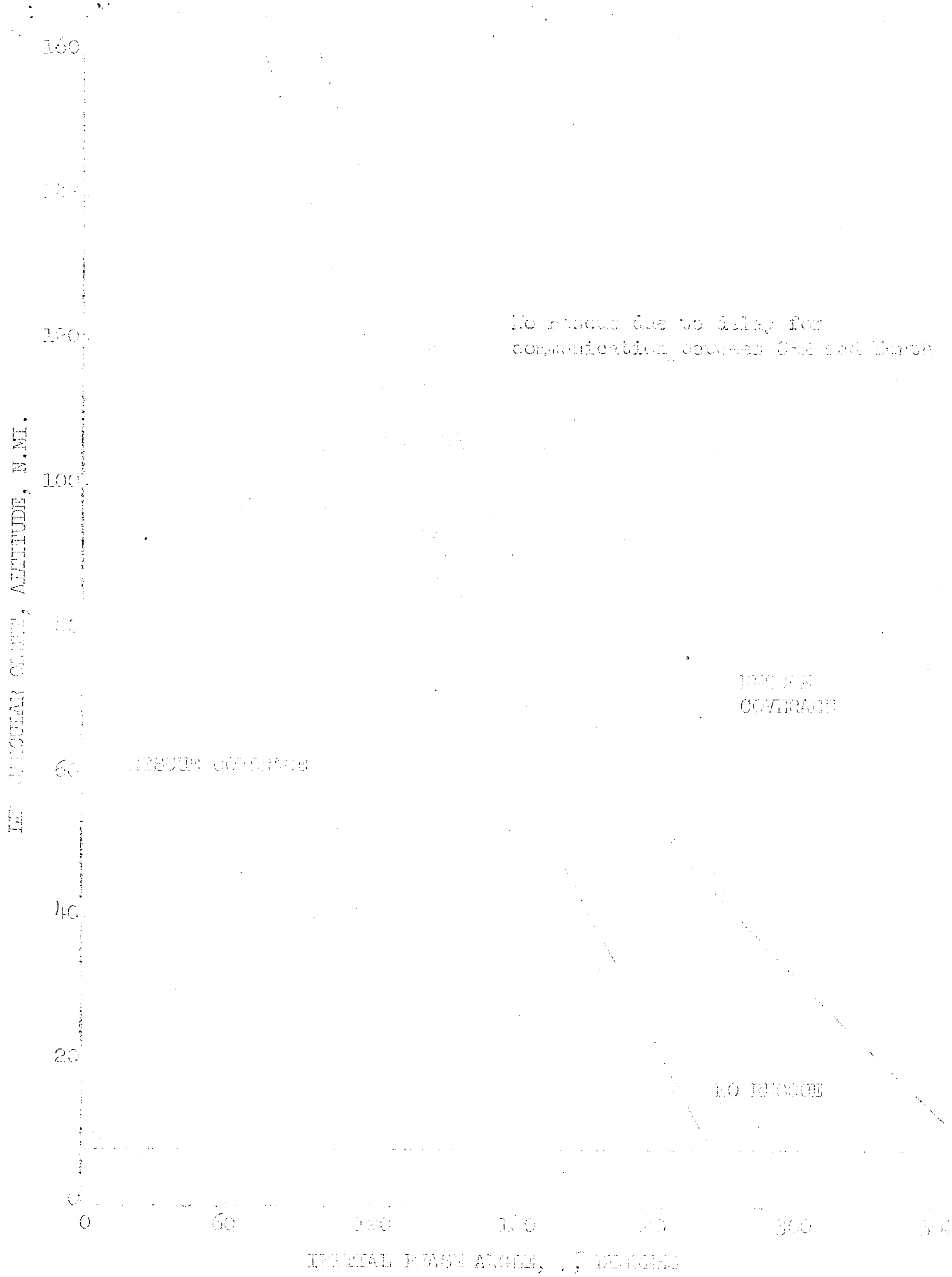

Figure 3.- Circular LM rescue coverage (1° out of plane)

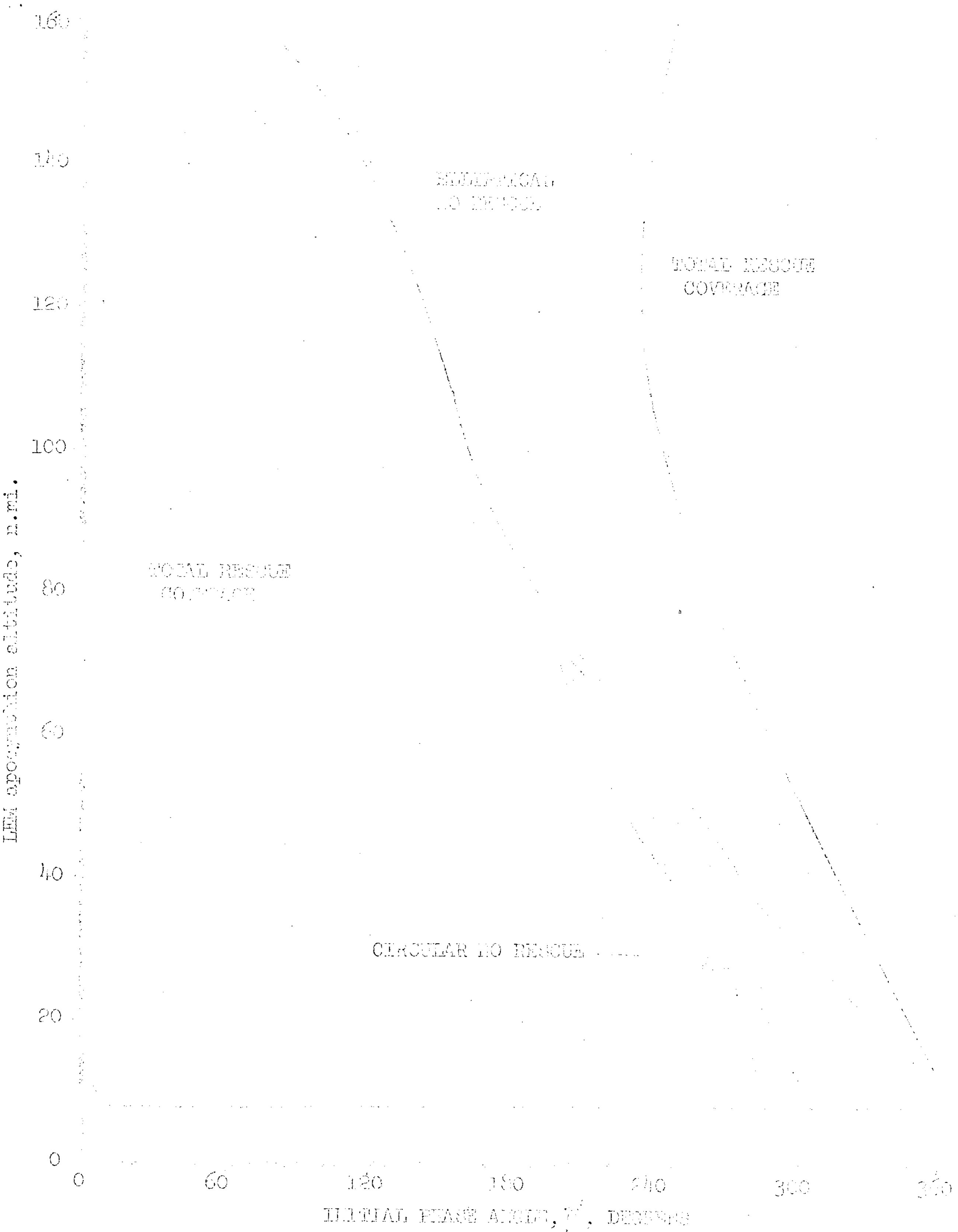

Figure 4.- Rescue coverage for elliptical LEM orbits

Pericynthion Altitude = 50,000 ft (In-plane)
Initial true anomaly of [illegible] = 0°

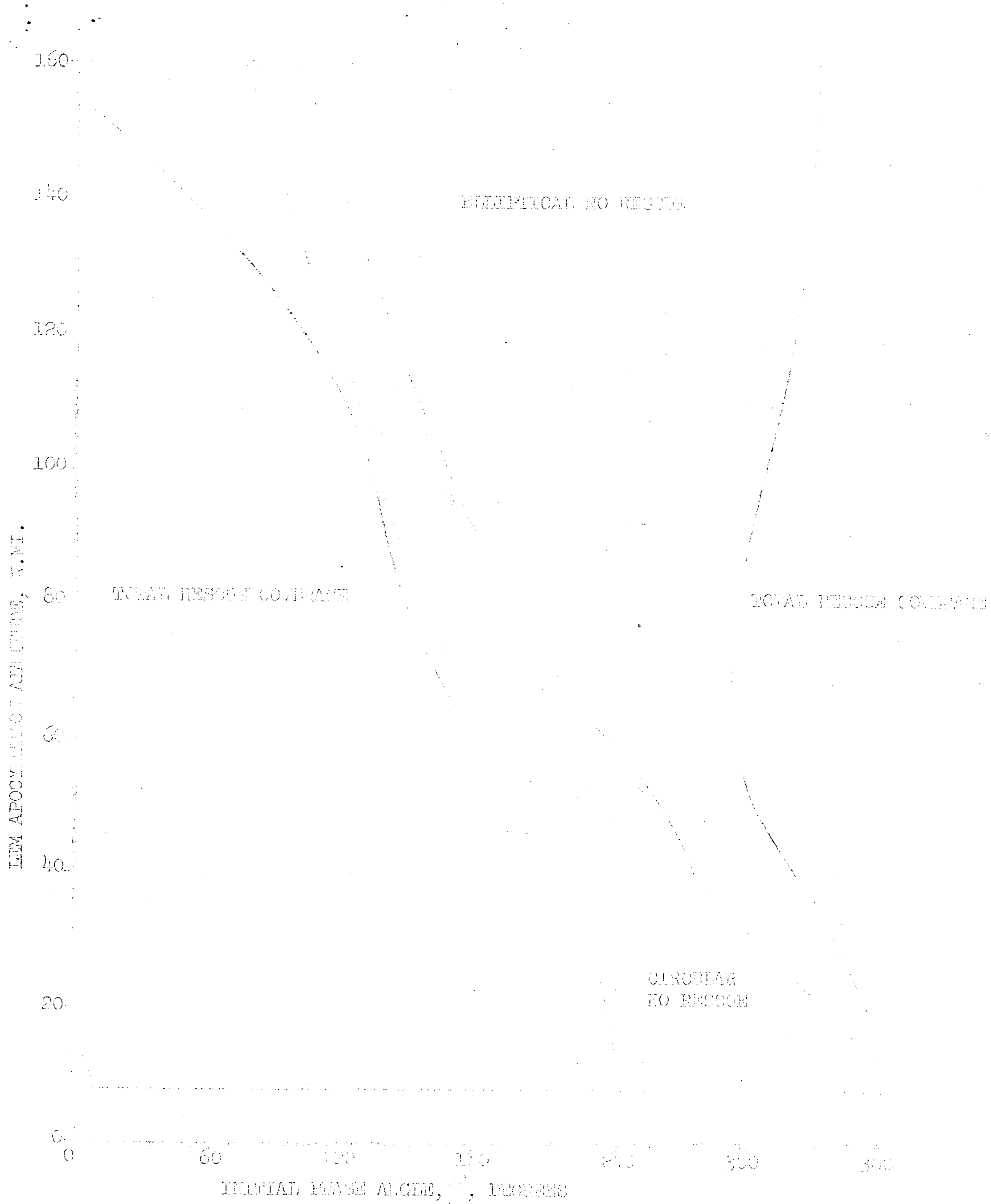

Figure 5.- Rescue coverage for elliptical LEM orbits
Pericynthion Altitude = 50,000 ft (1° out of plane)
Initial true anomaly of LEM = 0°

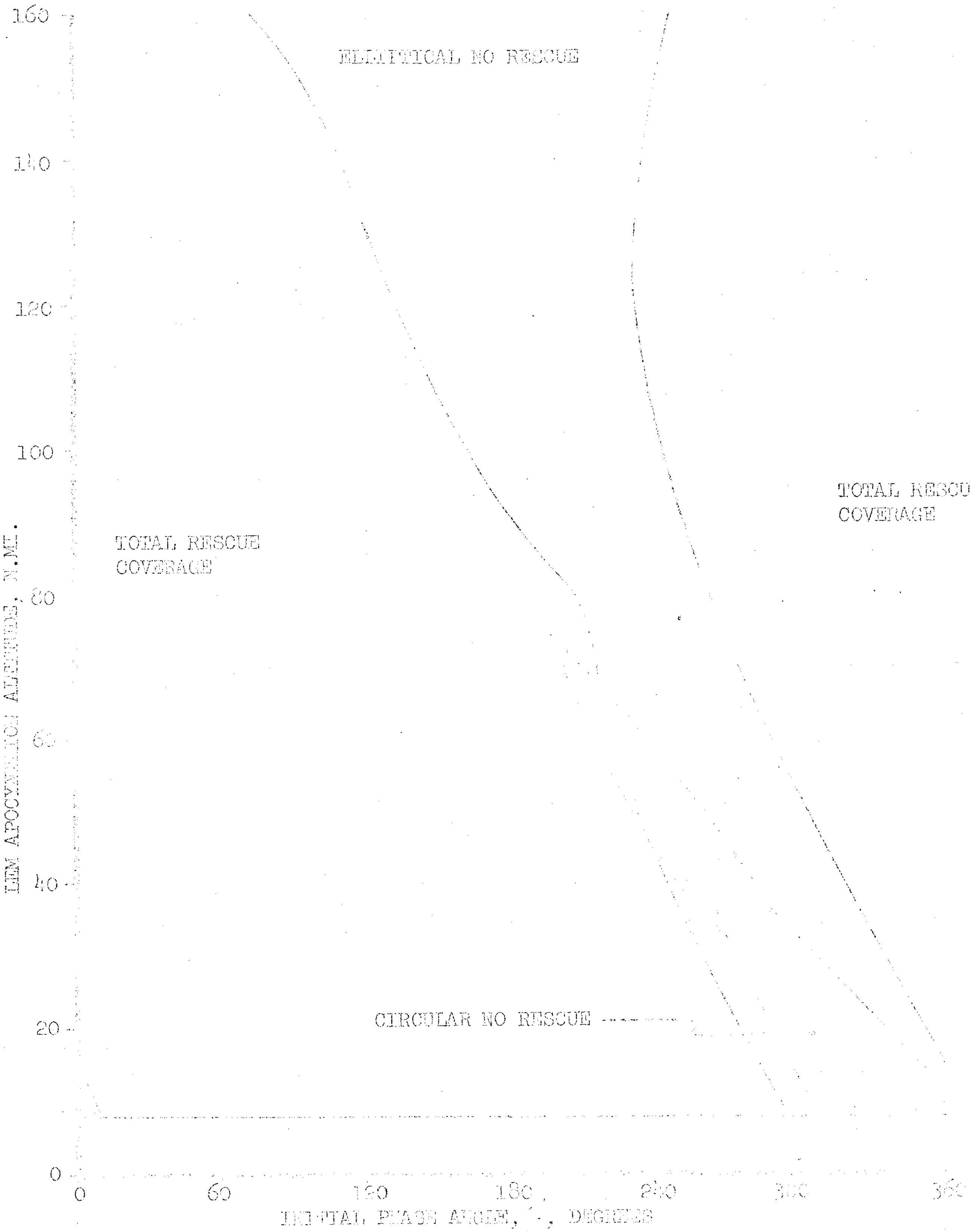

Figure 6.- Rescue coverage for elliptical LEM orbits
Pericynthion altitude = 50,000 ft. (in-plane)
Initial true anomaly of LEM = +45°

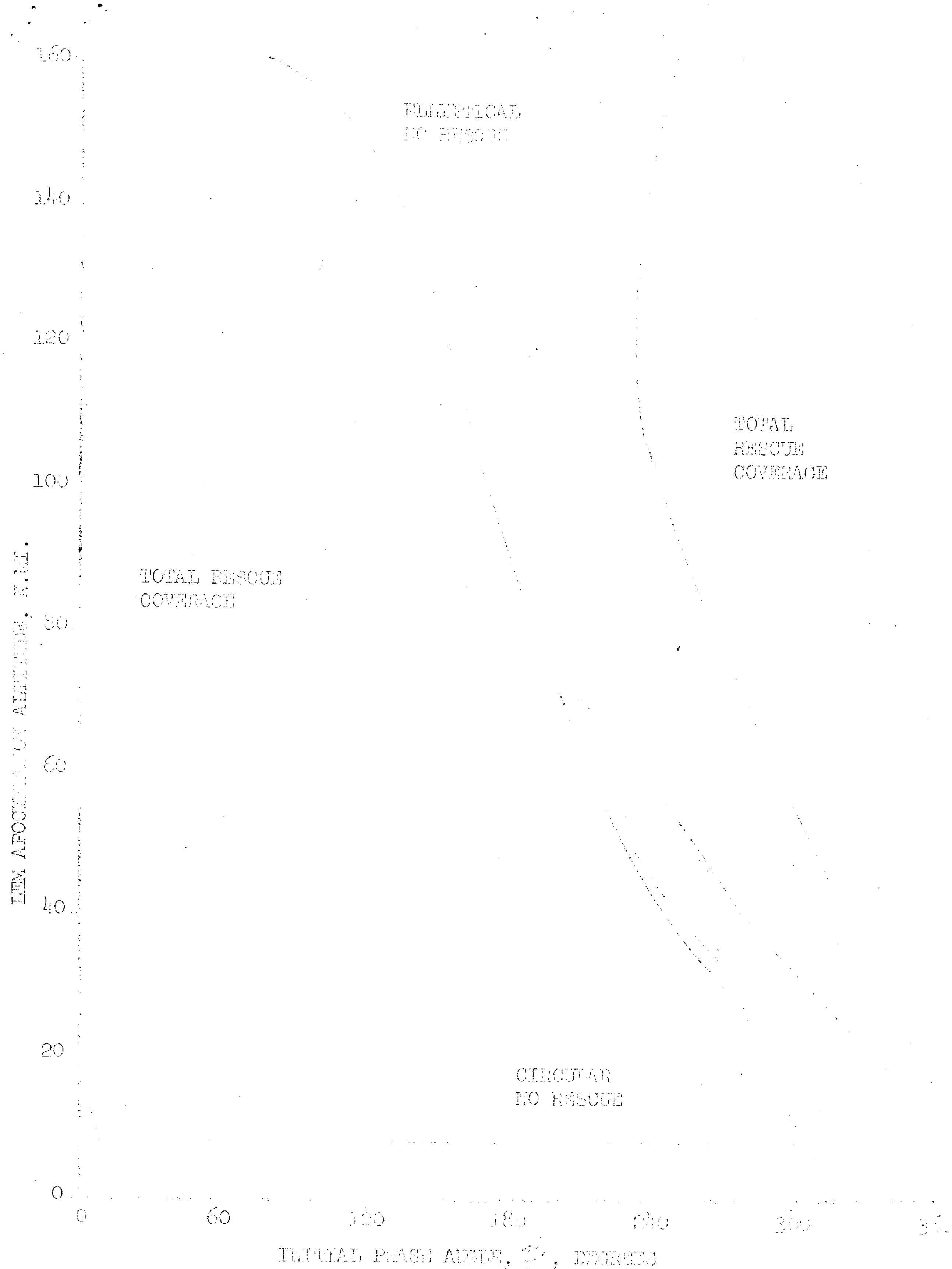

Figure 7.- Rescue coverage for elliptical LEM orbits

Pericynthion altitude = 50,000 ft (in plane)
Initial true anomaly of LEM = -45°

Figure 9.- Circular LEM orbit rescue coverage as determined by two methods (1° out of plane)

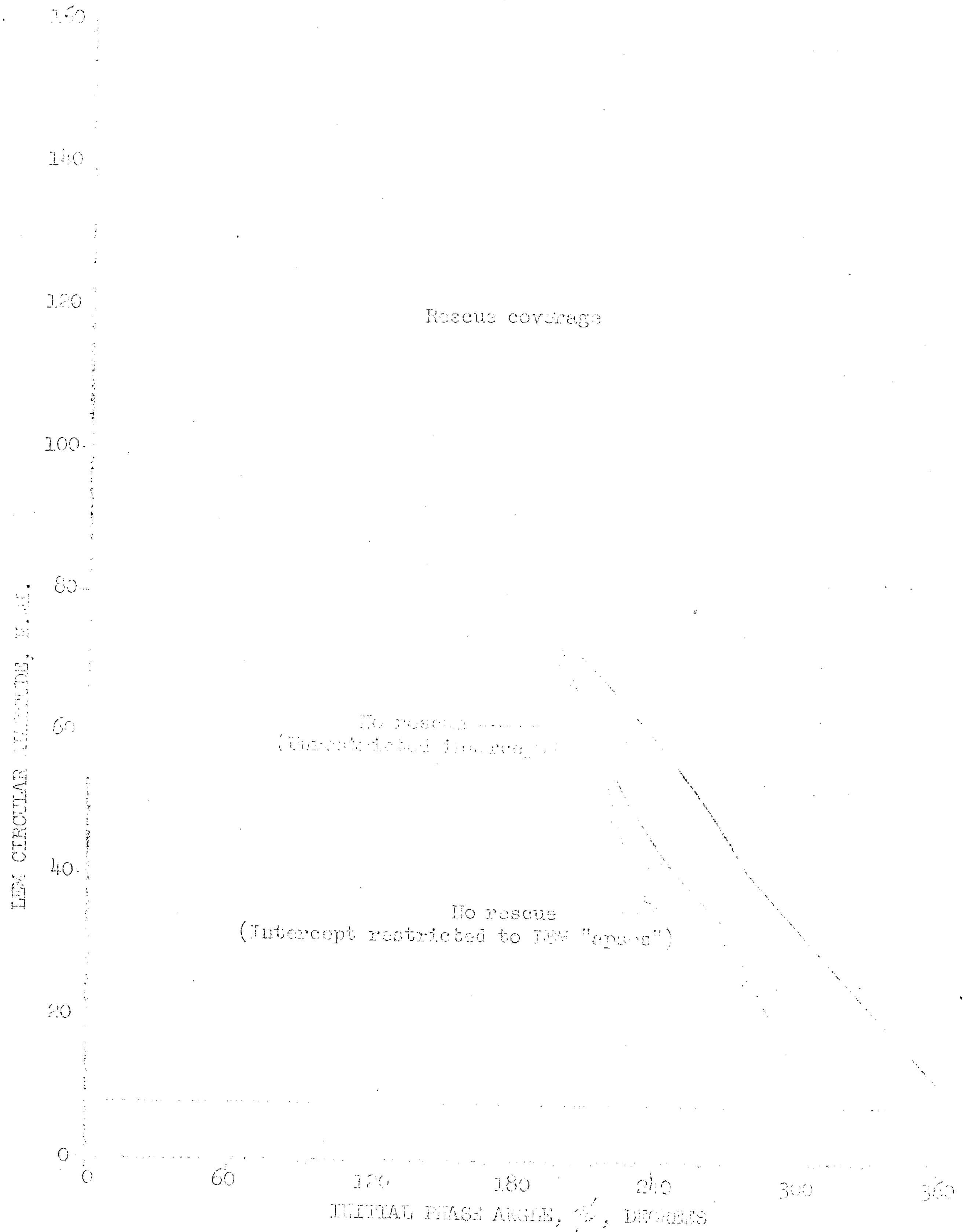

Figure 8.- Circular LEM orbit rescue coverage as determined by two methods (in plane)

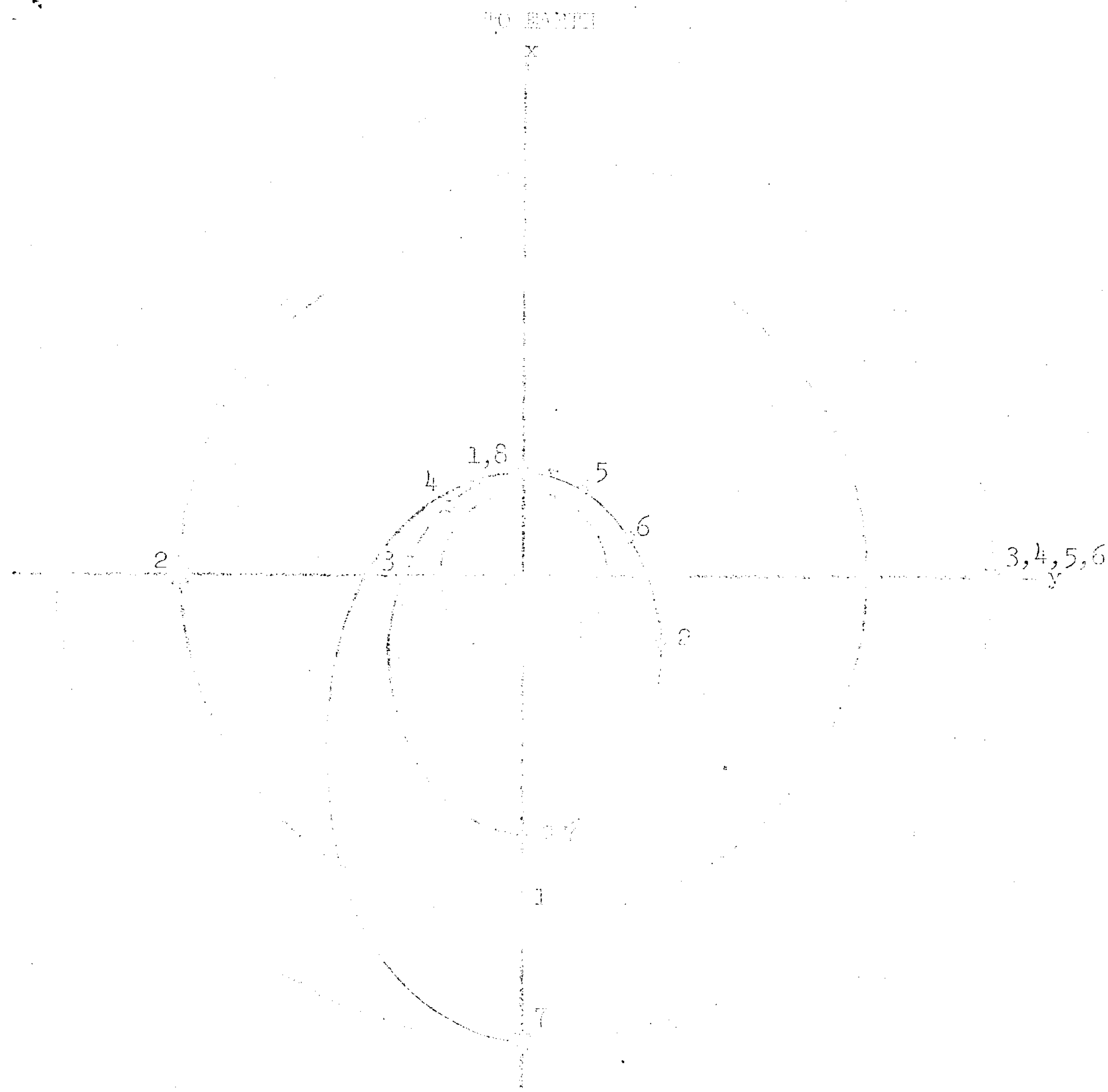

Figure 10.- Typical Rescue Maneuver

LEM h_p = 50,000 ft h_a = 60 n.mi. CSM h_c = 80 n.mi.

1 Initial conditions, phase angle = 180°
2 Earth notification of CSM
3 CSM has transferred to 114.[illegible] n.mi. circular orbit
4 Positions after 1 CSM period
5 " " 2 " "
6 " " 3 " "
7 " " $3\frac{1}{4}$ " "
8 Rendezvous at LEM pericynthion

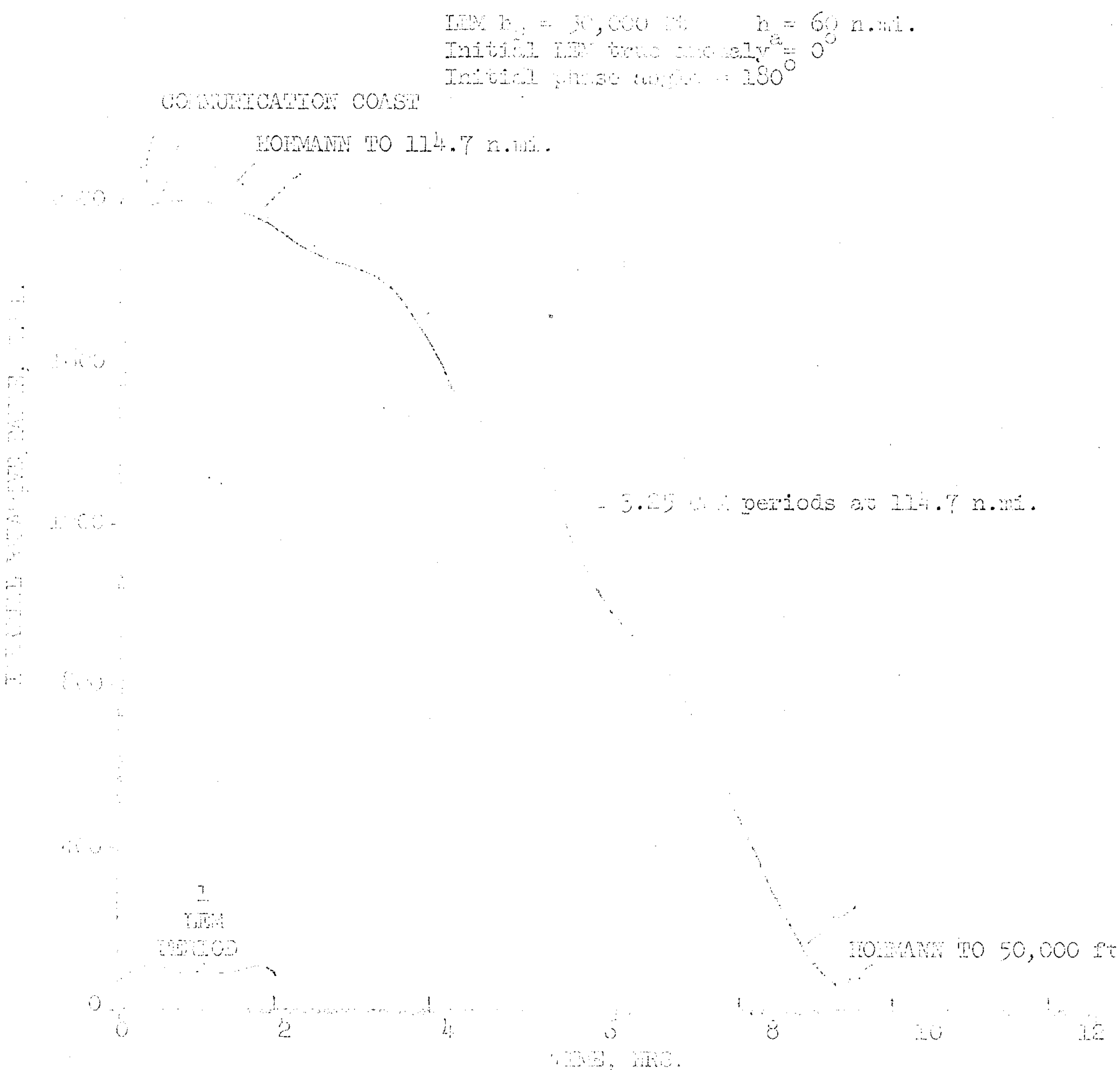

Figure 11.- Inertial relative range time history

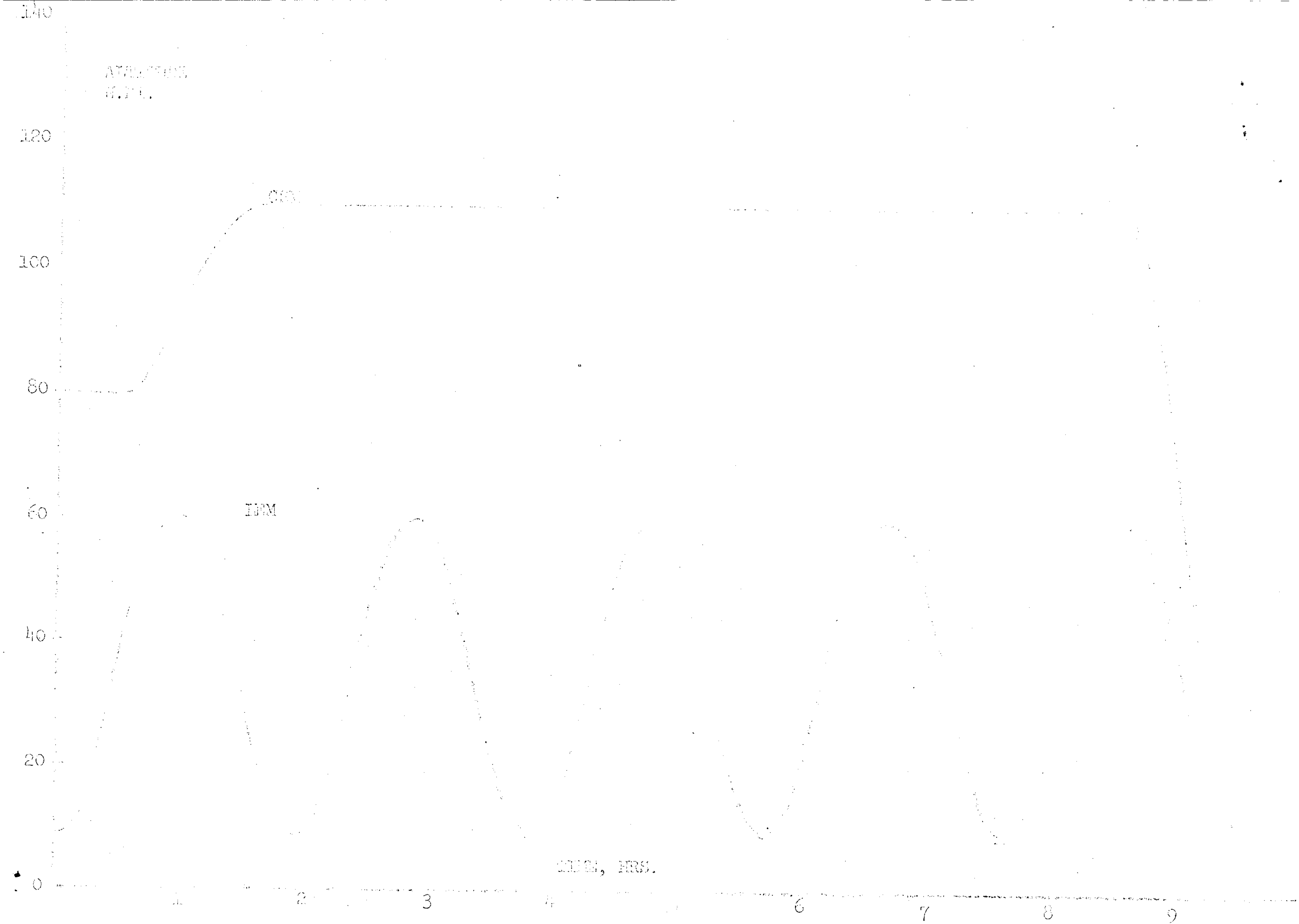

Figure 12.-Time history of altitude of LEM and CSM

Initial LEM true anomaly = 0°
Initial phase angle = 180°